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(54) Integral thin film injection system for thermal ink jet heads and methods of operation.

(57) A novel thermal ink jet printhead and related methods of operation are described. Methods of manufacture of the printhead wherein multiple heater resistors (18,20) are connected in series between a source of ink supply (10) and an output ink ejection orifice (24). A primary heater resistor (20) is located in an ink ejection chamber (16) and adjacent an output ink ejection orifice (24). This resistor (20) propels ink away from the printhead, whereas another heater resistor (18) (or resistors) is removed from the primary heater resistor (20) and is located in an adjacent ink injection chamber (14), and is operative to inject ink toward the primary heater resistor (20). In this manner, ink ejection operational frequency is increased and cavitational wear on the heater resistors (20) is minimized. Simultaneously, hydrodynamic back pressure in the ink ejection chamber (16) is reduced, and control over ink drop size and viscosity is improved.

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INTEGRAL THIN FILM INJECTION SYSTEM FOR THERMAL INK JET HEADS AND METHOD OF OPERATION

This invention relates generally to thermal ink jet (TIJ) printing and more particularly to such printing using multiple heater resistors to control ink drop ejection from a TIJ orifice plate

In the art of thin film resistor (TFR) substrate preparation for use in thermal ink jet printheads, one common practice has been to use one heater resistor for one or more orifices in an orifice plate for the printhead. This approach is described, for example, in the Hewlett Packard Journal, Vol. 38, No. 5, May 1985, incorporated herein by reference. While this approach has proven highly successful in many respects, the natural ink reservoir refill and fluid hydrodynamics associated with this single resistor-per-orifice configuration imposes an upper limit on both the operating frequency of ink ejection from the printhead and the variability and control of the ejected ink drop volume.

A general object of this invention is to provide a new and improved thermal ink jet printhead and method of operation which extends the upper limit of the ink ejection operational frequency, while simultaneously increasing the variability and control of drop volume of ink ejected from the printhead.

Another object of this invention is to provide a new and improved thermal ink jet printhead of the type described which is operative to reduce hydrodynamic back pressure and cavitation wear on certain heater resistors of the printhead structure.

Another object is to provide a new and improved thermal ink jet printhead of the type described which is operative to eject variable drop volumes of ink, thereby resulting in variable dot sizes.

Another object is to provide a new and improved thermal ink jet printhead of the type described which allows ink to be preheated to a preselected controlled temperature in order to exert control on the viscosity of the ink. Such operation maintains a desired and controlled viscosity level in the ink.

Another object is to provide a new and improved thermal ink jet printhead of the type described which is operative to impart controlled quantities of thermal energy to the ink, which in turn allows subsequent ejection of a drop or drops of ink with shorter duration and lower energy pulses.

A further object of this invention is to provide a new and improved thermal ink jet printhead of the type described which may be operated to limit underdamped oscillatory fluid waves through dynamic loading, thereby resulting in an enhanced operating frequency and improved harmonic control.

The above objects and related advantages and novel features of this invention are accomplished by the provision of an ink jet printhead assembly which includes means providing an ink flow path between an ink supply and an ink ejection orifice, and an ink injection chamber and a drop ejection chamber are located in series between the source of ink supply and an ink ejection orifice. The ink injection chamber contains at least one ink injection heater resistor and the drop ejection chamber contains at least one drop ejection heater resistor. Electrical pulse control means are connected to both the ink injection heater resistor and to the drop ejection heater resistor for sequentially pulsing these resistors to thereby reduce hydrodynamic back pressure from the drop ejection chamber. This switching action also reduces the impact of cavitational forces from the ink ejection orifice and normal to the major surface of the drop ejection heater resistor.

The present invention will become better understood from the following description of the accompanying drawings.

Figures 1A and 1B, respectively, are abbreviated schematic plan and cross section views of the thermal ink jet printhead according to the invention, and prior to the formation of an outer orifice plate thereon in Figure 1A.

Figure 2 is an isometric view corresponding to Figure 1A and also prior to receiving an outer orifice plate.

Figures 3A through 3C are cross-section views showing the formation of the thin film resistor (TFR) substrate portion of the printhead according to the invention.

Figures 4A and 4B are cross section and plan views respectively showing the addition of a barrier layer to Figure 3C. This barrier layer defines the ink reservoir geometry of the printhead.

Figure 5 is a cross-section view showing the disposition of an orifice plate on the top surface of the barrier layer in Figures 4A and 4B.

Referring now to Figures 1A and 1B, a supporting substrate 10 of either a semiconductor or a glass material is prepared to receive a barrier layer 12 thereon which defines the ink reservoir geometry of the printhead, including an ink injection chamber 14 and a drop ejection chamber 16. The ink injection chamber 14 is provided with an ink injection heater resistor 18, whereas the drop ejection chamber 16 is provided with a drop ejection heater resistor 20. An outer or top orifice plate 22 is provided as shown in Figure 1B

and has an output orifice 24 which is either precisely aligned with the drop ejection heater resistor 20 or is offset with respect thereto by a predetermined dimension or dimensions.

It should be understood that the heater resistors 18 and 20 are represented only schematically and would, in their actual construction, typically include an underlying passivation and heat control layer and a covering protection layer such as SiC or Si_3N_4 or both in addition to the lead-in conductors. All of these materials have been omitted in Figs. 1A and 1B for sake of brevity and illustrating the basic concept underlying the present invention.

The ink injection heater resistor 18 and the drop ejection heater resistor 20 are connected by way of conductive trace material (not shown in this figure) which has been patterned to form lead-in conductors for the heater resistors. These lead-in conductors are shown in Figures 3, 4 and 5 below and provide an electrical connection for conducting controlled current pulses to both the ink injection heater resistor 18 and the drop ejection heater resistor 20 during a thermal ink jet printing operation. Thus, when current is applied to the ink injection heater resistor 18, the ink in the ink injection chamber 14 is heated to boiling and is thus propelled into the drop ejection chamber 16 where, upon application of a pulse to the ink ejection resistor, the ink is finally propelled out of the output orifice 24. Simultaneously, the utilization of the ink injection heater resistor 18 in this manner serves to decrease the time in which it takes for ink entering the opening 26 to reach the drop ejection heater resistor 20. In this manner, the operational frequency range of the thermal ink jet printhead is extended.

The above operation further serves to reduce hydrodynamic back pressure and cavitation wear on the heater resistors of the printhead structures, and it also preheats the ink flowing to the drop ejection chamber. The latter feature serves to control the temperature of the ink, and thereby controls its viscosity.

The present invention further permits the modulation of ejected drop volume by phasing the heating pulses to the injection heater resistor 18 and the ejection heater resistor 20. When the injection heater 18 is pulsed before the ejection heater 20, a disturbance of the fluid meniscus in the orifice 24 is produced. The fluid in the orifice region 24 will have volume and kinetic energy controllable by the timing delay between the activation of the injection heater 18 and the ejection heater 20. The volume and kinetic energy of the fluid when the ejection heater 20 is subsequently activated provides a different initial condition to the drop ejection mechanism compared to the quiescent state where the ejection heater 20 is activated alone. This mechanism allows for the modulation of the drop volume both above and below the nominal value obtained when the ejection heater 20 is activated alone.

Referring now to Figure 2, the printhead structure shown in isometric view is also shown without the conductive trace leads connected to heater resistors 18 and 20 and without the top orifice plate applied to the barrier layer 12. This figure is useful to show the general position of the two heater resistors 18 and 20 with respect to the ink flow path into the ink injection chamber 14 and by way of convergent barrier wall sections 28 and 30 which define the width dimension of the ink flow input port 26. The convergent contours of the barrier walls 28 and 30 are utilized to constrict ink flow into the ink injection chamber and thereby provide the necessary hydraulic tuning for optimizing the ink ejection efficiency of the thermal ink jet printhead. For a further discussion of this hydraulic tuning and related fluidic control techniques, reference may be made to copending European application serial number 88310139.6 of Kenneth Trueba et al and assigned to the present assignee.

Referring now to Figures 3A through 3C, a silicon or glass substrate 32 is typically used as the thin film resistor substrate starting material and is treated in a conventional manner, such as by etching and polishing, to receive a surface layer 34 of resistive heater material, such as tantalum-aluminum. The resistive heater layer 34 is in turn adapted to receive a layer 36 of conductive trace material, such as aluminum or gold. The conductive trace layer 36 is configured using conventional photolithographic masking and etching processes to provide openings 38 and 40 therein as shown in Figure 3B. The openings 38 and 40 in the conductive trace layer 36 in turn define the length and width dimensions of a pair of heater resistors 42 and 44 which, of course, correspond to the schematically represented heater resistors 20 and 18 in the schematic and abbreviated views of Figures 1 and 2.

After the structure in Figure 3B is completed, it is transferred to a dielectric layer deposition station wherein a resistive heater barrier layer 46 is provided as shown in Figure 3C to insulate the underlying heater resistors 42 and 44 and the conductive trace material 36 in Figure 3B from ink corrosion and cavitation wear. This surface barrier layer 46 will typically consist of a combination of an initial thin layer of silicon nitride on top of which an outer layer of silicon carbide is formed using known nitride and carbide deposition techniques. The Si_3N_4 portion of the barrier layer 46 provides a good materials match with the underlying layers of TaA1 and metal, and the SiC outer portion of the barrier layer 46 provides a highly inert outer protective film to insulate the underlying materials against ink corrosion.

Once the structure in Figure 3C has been completed, it is transferred to another barrier deposition and

geometry forming station wherein a second or ink reservoir-defining barrier layer 48 is provided in the geometry shown in Figures 4A and 4B. The second or outer surface barrier layer 48 is masked and etched using conventional state-of-the-art photolithographic masking and etching techniques in order to form an opening 50 which now defines the length and width dimensions of the ink injection chamber and the drop ejection chamber. These chambers are located approximately at the reference numerals 52 and 54 and above the ink injection and drop ejection resistors 44 and 42, respectively.

Referring now to Figure 5, there is shown the addition of the top orifice plate 56 having a convergent orifice therein which terminates at an output opening 58 and includes a converging and smoothly contoured surface 60. The output orifice opening 58 is aligned with respect to the drop ejection heater resistor 42, and in some applications a small offset between orifice plate opening 58 and heater resistor 42 may be preferred. Thus, ink traversing the flow path indicated at the arrow 62 will enter the ink injection chamber 52 above the ink injection resistor 44 and then proceed to flow into the drop ejection chamber 54 atop the drop ejection heater resistor 42 in a manner previously described.

As indicated in the following TABLE, the outer barrier layer 48 may be constructed of well known polymer materials, such as materials known as RISTON or VACREL and sold by the Dupont Co. of Wilmington, Delaware. Alternatively, the outer surface barrier layer 48 may be a metal such as nickel and electroformed using processes such as those described in the above identified Hewlett-Packard Journal.

The orifice plate 56 may be manufactured from metal or plastic using known fabrication techniques, and when a metal such as nickel is used for forming both the barrier layer 48 and the orifice plate 56, then one may prefer to employ the electroforming processes disclosed in allowed copending European application No.87900407.5 of Chor S. Chan et al entitled "Barrier Layer and Orifice Plate For Thermal Ink Jet Printhead Assembly", assigned to the present assignee and incorporated herein by reference.

The following table of values indicates suitable layer deposition processes, layer thicknesses, materials, and some resistivities which may be used in printhead manufactured in accordance with the present invention. However, it should be understood that this table is given by way of example only, and it is not intended to indicate any single best process for manufacturing our printhead, since one single preferred process and materials set has not been selected at the present time.

Table

LAYER	SUITABLE MATERIAL	DEPOSITION PROCESS	THICKNESS (MICRONS)	RESISTIVITY $\times 10^{-6}$
Insulating Substrate (1)	Oxidized Silicon Glazed Ceramic Glass Silicon Oxynitride	Thermal Oxidation		
Resistor Layer (2)	Tantalum Aluminum Tantalum Nitride	Sputtering	0.02 to 0.3	100 to 300
Conductor Layer (3)	Aluminum Aluminum Copper Alloy Aluminum Si Alloy Gold	Sputtering	0.5 to 2.0	2 to 3
Passivation Layer (6)	Silicon Nitride Silicon Carbide Silicon Di Oxide Silicon Oxynitride	PECVD* LPCVD**	0.5 to 2.0	
Barrier Layer Layer (7)	Riston Vacrel Nickel	Lamination Plating	10 to 75	
Orifice Plate (10)	Nickel Gold Plated Ni Plastic	Plating Forming	20 to 75	

100000 Å,
750,000 Å

* Plasma Enhanced Chemical Vapor Deposition
** Liquid Phase Chemical Vapor Deposition

In the above table, PECVD signifies plasma enhanced chemical vapor deposition, whereas LPCVD signifies liquid phase chemical vapor deposition. These processes are generally well known in the thin film art and are therefore not described in further detail herein. However, for a further discussion of these or related thin film technologies, reference may be made to the following three books on thin film technology:

(1) Berry, Hall and Harris, Thin Film Technology, Van Nostrand Reinhold Co., New York, 1968.
(2) Maissel and Glang, Handbook of Thin Film Technology, McGraw Hill Book Co., New York, 1970.
(3) Vossen and Kern, Thin Film Processes, Academic Press, New York, 1978.

Various modifications may be made in the above described embodiment without departing from the scope of this invention. For example, in some applications it may be desired to electrically connect the two resistors 18 and 20 in parallel rather than in series. In such an alternative connection, appropriate timing of the control pulses can be used to establish the desired firing times for the ink injection and drop ejection heater resistors. In addition, for other applications it may be preferred to change the geometry and alter the spacing of both the heater resistors and their surrounding reservoir walls in order to be more compatible with a particular type of ink jet printhead geometry or electrical lead-in configuration.

Claims

1. An ink jet printhead characterised in that it includes an ink flow path between an ink supply chamber (10) and an ink ejection orifice (24), the ink flow path having a plurality of resistive heaters (18,20) disposed along its length.

2. The ink jet printhead of claim 1 wherein the resistive heaters (18,20) lie on the floor of the ink path, one behind another, along the length of the ink flow path.

3. The ink jet printhead of claim 1 or 2 wherein the resistive heaters (18,20) make up a plurality of units each unit containing one or more adjacent resistive heaters (18,20).

4. The ink jet printhead of claim 3 wherein each unit is individually controllable.

5. The ink jet printhead of claim 4 wherein the units are electrically pulsed in a periodic manner, the phase difference between pulses to adjacent units being chosen to minimise hydrodynamic back pressure from the section of the ink flow path (14) adjacent to the ink supply chamber (10) and to minimise cavitational forces directed against resistive heaters (18,20) near to the ink ejection orifice (24).

6. The ink jet printhead of any preceding claim wherein the ink flow path is a continuous ink reservoir which extends from the ink supply chamber (10) to the ink ejection orifice (24).

7. A method of ejecting ink from a thermal ink jet printhead using phased energisation of a plurality of resistive heaters (18,20) along the ink flow path.

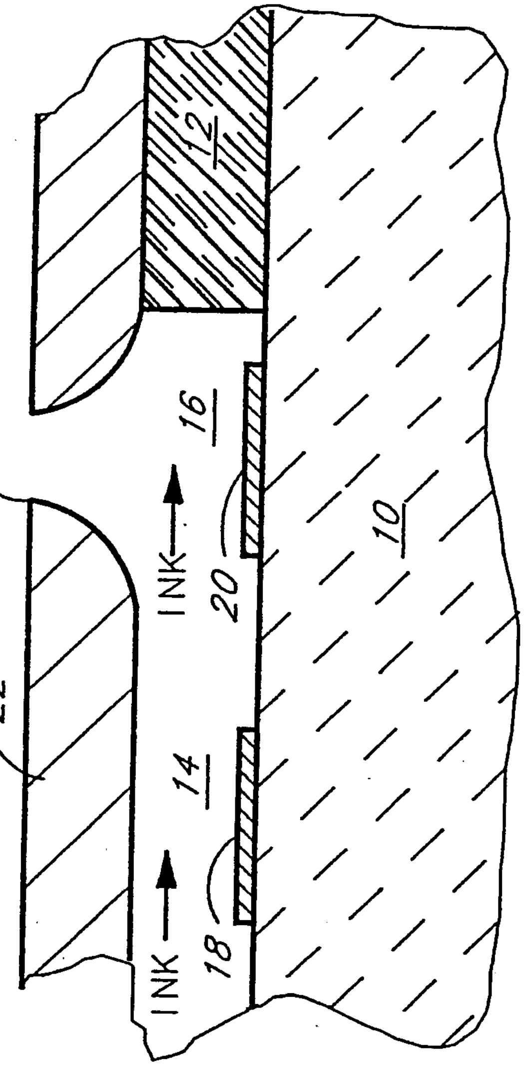

FIG 1B

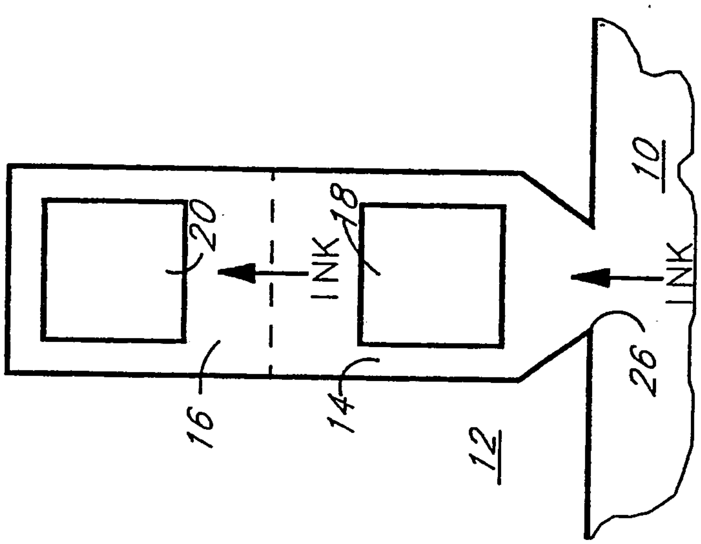

FIG 1A

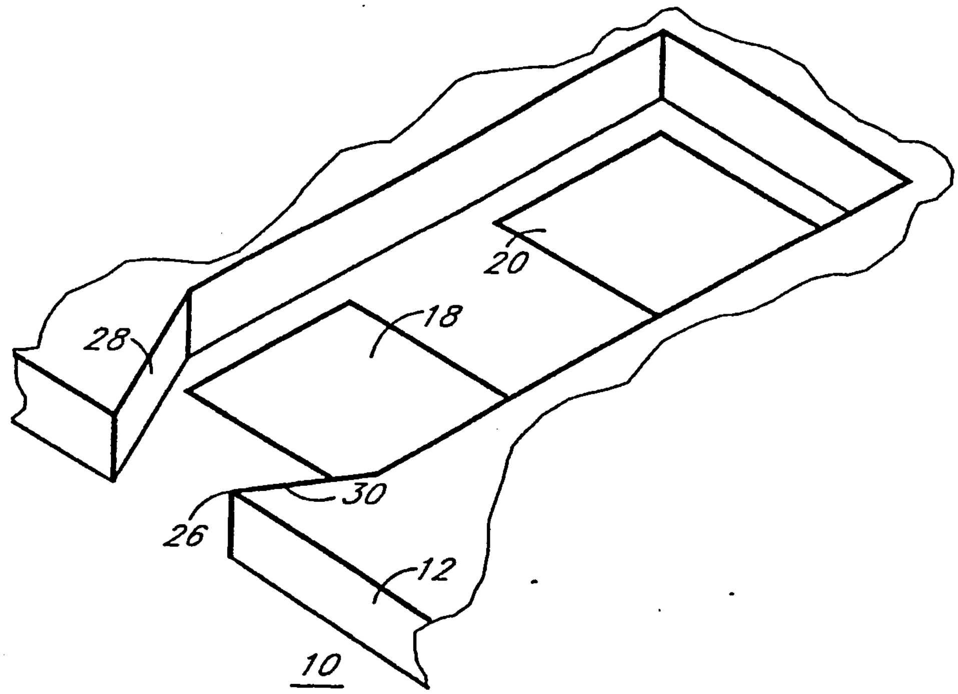

FIG 2

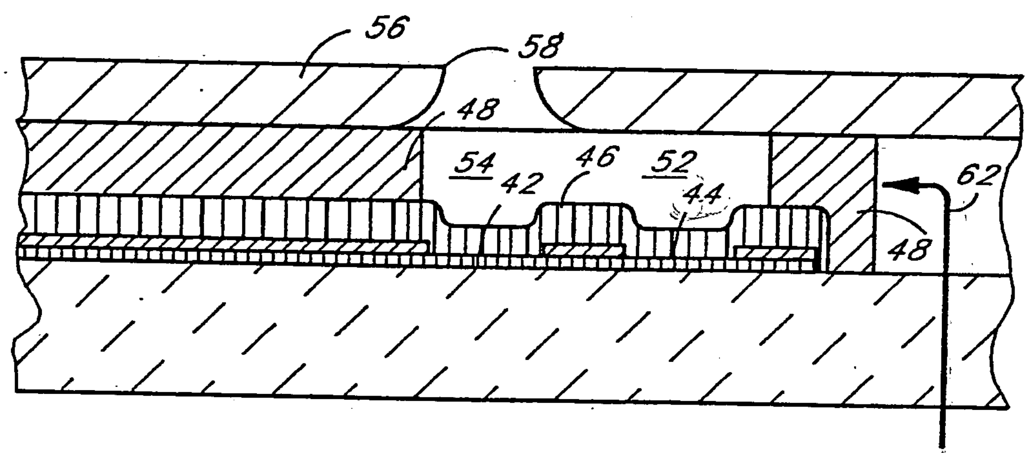

FIG 5

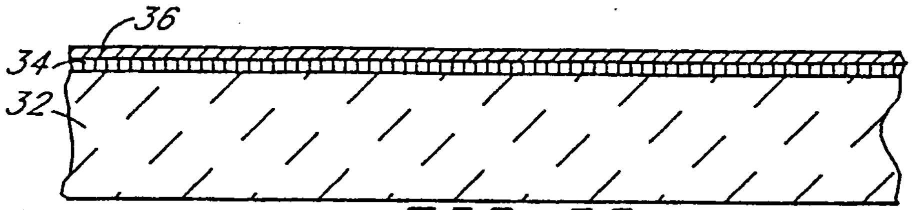

FIG 3A

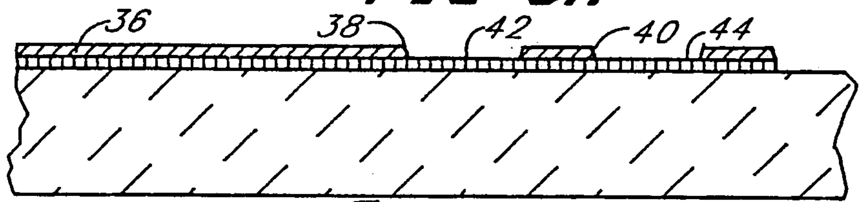

FIG 3B

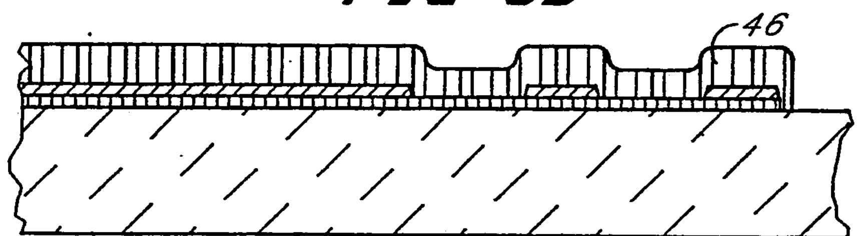

FIG 3C

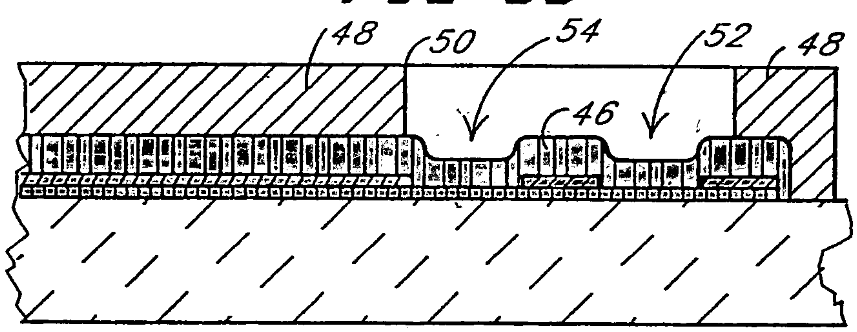

FIG 4A

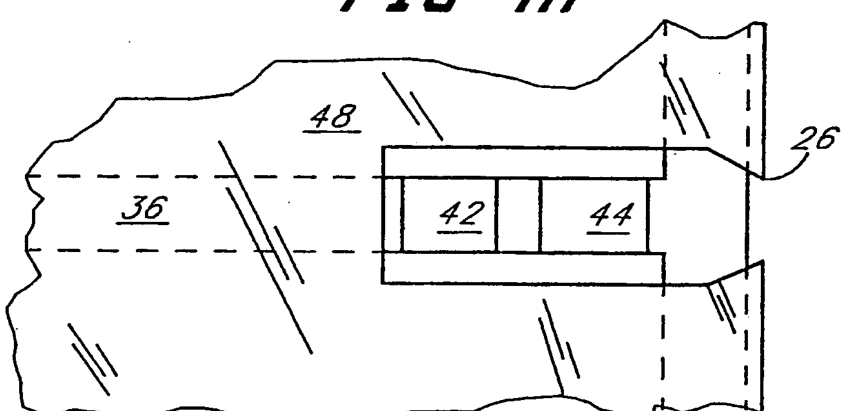

FIG 4B